Effects of Court Specific and Minimalist Footwear on the Biomechanics of a Maximal 180° Cutting Manoeuvre

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EFFECTS OF COURT SPECIFIC AND MINIMALIST FOOTWEAR ON THE BIOMECHANICS OF A MAXIMAL 180° CUTTING MANOEUVRE

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ABSTRACT
Purpose. The aim of the current investigation was to examine the effects of different footwear on the kinetics and kinematics of performing a 180° cutting manoeuvre.
Methods. Nine male participants performed maximal 180° cut movements in court shoes, minimalist footwear, energy return, and conventional running shoes. Lower limb kinematic data were collected with the use of an 8 camera motion capture system, ground reaction forces were quantified with an embedded force platform, and tibial accelerations were obtained by means of an accelerometer. Differences in kinetics and kinematics between footwear were examined by one-way repeated measures ANOVA.
Results. The results showed that both instantaneous loading rate and peak tibial acceleration were significantly larger in the minimalist (282.91 BW/s and 6.38 g) and court (326.67 BW/s and 6.35 g) footwear compared with the conventional (143.19 BW/s and 5.46 g) and energy return (106.14 BW/s and 4.98 g) footwear. In addition, peak inversion was revealed to be significantly larger in the minimalist (16.36°) than in conventional (11.86°), court (12.61°), and energy return (10.12°) footwear.
Conclusions. These findings indicate that minimalist and court footwear may place athletes at increased risk from injury when performing 180° cut movements.
Key words: footwear, biomechanics, kinematics, change of direction

Introduction

There is a significant amount of literature which has examined the mechanics of linear velocity using straight-line movements. However, linear sprinting is not ecologically related to the majority of athletic disciplines, particularly court sports [1]. Court sports involve a range of different activities which typically include running, jumping, and rapid changes of direction (cutting moves) [2]. The ability to change direction is essential for successful performance within multidirectional court sports, providing athletes with a mechanism to gain positional advantage on the court [3].

Previously published work evaluating change of direction activities is limited. However, it has been noted that change of direction tasks place high stresses upon the lower extremity [4], meaning that the potential for injury is high. The goal of athletic footwear for court based activities is to improve performance and to protect participants from injuries. Athletic footwear with appropriate mechanical characteristics has been proposed as a mechanism by which injury risk can be controlled [5]. The attenuation of impact loading and the promotion of lateral stability are the two most important footwear mechanisms that are required by athletes who are involved in court sports [6]. Typically, athletes involved in court sports utilize either court specific footwear or running shoes. Court footwear is characterized by construction features aimed at maximizing lateral support stability. Running shoes now vary considerably and may include conventional cushioned running footwear, minimalist footwear which features minimal midsole cushioning and a negligible heel to toe drop, and energy return footwear utilizing a thermoplastic polyurethane midsole designed to reduce the amount of energy loss associated with each foot contact [7].

The effects of different footwear on change of direction tasks have received comparatively little research attention in relation to linear running, and thus there is a lack of scientific consensus regarding the most appropriate shoes for court sports. Therefore, a range of different footwear are currently used for court based activities [8]. Sinclair et al. [9] investigated the effects of minimalist and court specific footwear on the kinetics and kinematics

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of a 45° cut task. Their findings showed that minimalist footwear was associated with significantly larger impact loading parameters in comparison with the court specific condition. Similarly, Sinclair et al. [10] examined the influence of minimalist and court footwear on the loads experienced by the patellofemoral joint and Achilles tendon during a 45° cut movement. The results of this study proved that the forces experienced by the patellofemoral joint were reduced in minimalist footwear but the loads borne by the Achilles tendon were correspondingly increased. Stacoff et al. [11] investigated the effects of performing cutting movements whilst barefoot and in five prototype shoes. The findings showed that lateral stability was significantly improved in the barefoot condition. There is currently no published information relating to the effects of different footwear on the biomechanics of 180° cut movements.

Therefore, the aim of the present investigation was to examine the effects of court shoes, minimalist footwear, energy return footwear, and conventional running shoes on the kinetics and kinematics of performing a 180° cutting manoeuvre. Research of this nature may provide important new information to athletes regarding the selection of appropriate footwear for court based activities.

Material and methods

Participants

Nine male participants volunteered to take part in this study. All participants were competitive athletes who performed the experimental movement regularly and were recruited from university level sports teams.

The mean characteristics of the participants were: age 24.55 ± 2.77 years, height 177.22 ± 5.37 cm, and body mass 73.67 ± 7.05 kg. All were free from lower extremity pathology at the time of data collection and provided written informed consent in accordance with the Declaration of Helsinki. The procedure was approved by the University ethics committee.

Procedure

Participants were instructed to perform maximal shuttle run cutting manoeuvres whilst striking an embedded force platform (Kistler, Kistler Instruments Ltd., Alton, Hampshire; length, width, height = 0.6 × 0.4 × 0 m) with their right (dominant) foot [12]. Limb dominance was assessed qualitatively by asking participants which foot they would utilize to kick a ball. The force platform sampled at 1000 Hz. Participants commenced their trials from 6 m away from the force platform, which was delineated with a masking tape [9]. This distance was selected as being approximately half the width of a tennis court and the full width of a squash court, which was deemed to be typical of the distances that court players may be expected to run and then change direction. The stance phase was delineated as the duration over which > 20 N of vertical force was applied to the force platform [13]. Five successful trials were obtained in each footwear condition. A successful trial was defined as one in which the foot made full contact with the force platform and there was no evidence of gait modifications due to the experimental conditions. The order in which participants performed in each footwear condition was counterbalanced. To ensure that participants utilized a similar approach speed in each of the experimental footwear, the linear velocity of the anterior superior iliac spines markers were quantified. The approach velocity during the first trial was calculated and a maximum deviation of 5% from this velocity allowed.

Kinematics and ground reaction force information was synchronously collected. Kinematic data were captured at 250 Hz via an 8 camera motion analysis system (Qualisys Medical AB, Göteborg, Sweden). Lower extremity segments were modelled in 6 degrees of freedom with the use of the calibrated anatomical systems technique [14]. To define the segment co-ordinate axes of the right foot, shank and thigh, retroreflective markers were placed unilaterally onto the 1st metatarsal, 5th metatarsal, calcaneus, medial and lateral malleoli, medial and lateral epicondyles of the femur. To define the pelvis segment, further markers were positioned onto the anterior (ASIS) and posterior (PSIS) superior iliac spines. Carbon fibre tracking clusters were positioned onto the shank and thigh segments. The foot was tracked with the 1st metatarsal, 5th metatarsal, and calcaneus markers, and the pelvis with the ASIS and PSIS markers. The centres of the ankle and knee joints were delineated as the mid-point

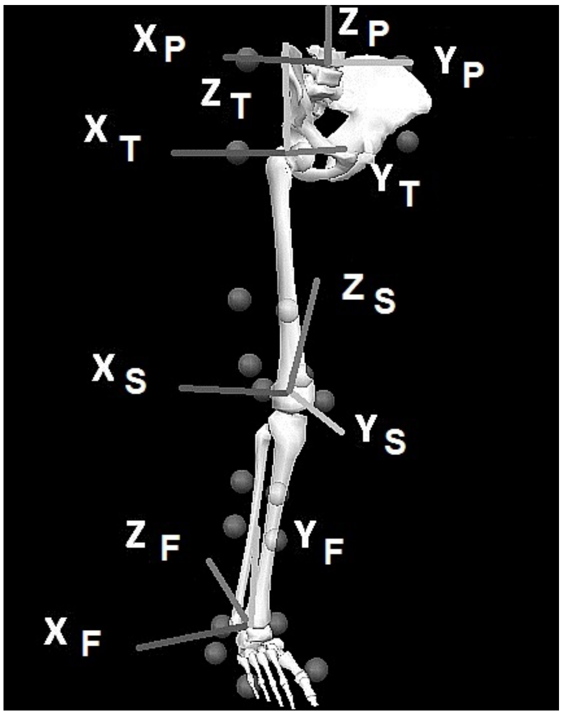

Figure 1. Lower body segments, with segment co-ordinate system axes. P – pelvis, S – shank, T – tibia, F – foot

between the malleoli and femoral epicondyle markers [15, 16], whereas the hip joint centre was obtained with the positions of the ASIS markers [17]. Static calibration trials (not normalized to static trial posture) were performed in each footwear, allowing for the anatomical markers to be referenced in relation to the tracking markers/clusters. The Z (transverse) axis was oriented vertically from the distal segment end to the proximal segment end. The Y (coronal) axis was oriented in the segment from posterior to anterior. Finally, the X (sagittal) axis was determined with the right hand rule and was oriented from medial to lateral (Figure 1).

To measure distal accelerations at the tibia, an accelerometer (Biometrics ACL 300, Gwent, United Kingdom) sampling at 1000 Hz was used. The accelerometer was attached onto a piece of lightweight carbon-fibre material in accordance with the protocol outlined by Sinclair et al. [18]. The tibial accelerometer was strapped securely to the distal anterior medial aspect of the tibia in alignment with its longitudinal axis 0.08 m above the medial malleolus [19]. Strong non-stretch adhesive tape was placed over the device and leg to avoid overestimating the acceleration owing to tissue artefact.

Experimental footwear

The footwear used during this study consisted of conventional footwear (New Balance 1260 v2), minimalist (Vibram five-fingers, ELX), court shoes (Hi-Tec Indoor Lite), and energy return footwear (Adidas energy boost) (shoe size 8–10 in UK men's sizes) (Figure 2). The minimalist footwear had an average mass of 0.167 kg, heel thickness of 7 mm, and a heel drop of 0 mm. The conventional footwear had an average mass of 0.285 kg, heel thickness of 25 mm, and a heel drop of 14 mm. The court shoes had an average mass of 0.368 kg, heel thickness of 28 mm, and a heel drop of 10 mm. Finally, the energy return condition had an average mass of 0.265 kg, heel thickness of 24 mm, and a heel drop of 10 mm.

Processing

Trials were processed in Qualisys Track Manager and then exported as C3D files. Kinematic parameters were quantified with Visual 3-D (C-Motion Inc, Gaithersburg, USA) after marker data were smoothed by means of a low-pass Butterworth 4th order zero-lag filter at the cut off frequency of 15 Hz [20]. The kinematics of the hip, knee, ankle, and tibial segment was quantified with an XYZ cardan sequence of rotations (where X is flexion-extension, Y is ab-adduction, and Z is internal-external rotation). All data were normalized to 100% of the stance phase then processed trials were averaged. 3-D kinematic measures from the hip, knee, ankle, and tibia extracted for statistical analysis were: 1) angle at footstrike, 2) peak angle, and 3) angular range of motion (ROM) from footstrike to peak angle.

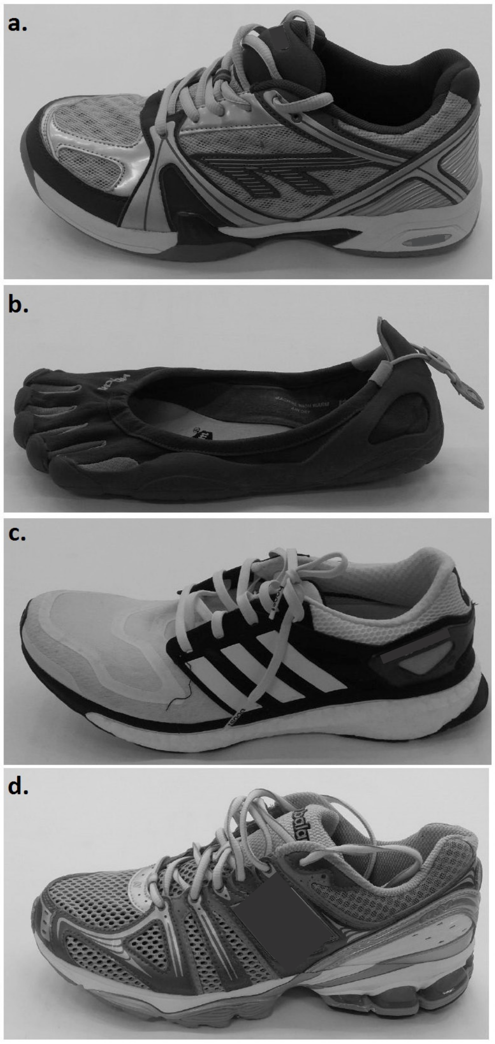

Figure 2. Experimental footwear (a. court shoes, b. minimalist footwear, c. energy return, d. conventional footwear)

From the force platform, instantaneous loading rate (BW/s) was calculated as the maximum increase in vertical force between adjacent data points. The acceleration signal was filtered with a 60-Hz low-pass Butterworth 4th order zero-lag filter [19]. Peak tibial acceleration was defined as the highest positive acceleration peak measured during the stance phase. Tibial acceleration slope (g/s) was quantified by dividing the peak tibial acceleration magnitude by the duration over which the acceleration occurred. Finally, tibial acceleration instantaneous slope (g/s) was calculated as the maximum increase in tibial acceleration between adjacent data points.

Analyses

Means and standard deviations were calculated for each outcome measure for all footwear conditions. Differences in kinetic/kinematic parameters between footwear were examined with one-way repeated measures ANOVAs, with significance accepted at the $p \leq 0.05$ level.

Effect sizes were calculated with the use of partial eta² (η^2). Effect sizes were characterized in accordance with Cohen [21], small = 0.2, medium = 0.5, and large = 0.8. Minimal clinically important differences (MCID) were also determined for each measurement as being equal to the pooled standard error between footwear [22]. Post-hoc pairwise comparisons were conducted on all significant main effects. The data were screened for normality with the Shapiro-Wilk test, which confirmed that the normality assumption was met. All statistical actions were conducted with SPSS v22.0 (SPSS Inc., Chicago, USA).

Results

Figure 3 and Tables 1–4 present the footwear differences in kinetics and kinematics. The results indicate that the experimental footwear significantly affected both kinetic and kinematic parameters.

Kinematics

Hip

No significant ($p > 0.05$) differences in hip joint kinematics were observed between the footwear.

Knee

No significant ($p > 0.05$) differences in knee joint kinematics were observed between the footwear.

Ankle

In the sagittal plane, a main effect ($p = 0.04$, $\eta^2 = 0.26$) was shown for the angle at footstrike. Post-hoc pairwise comparisons revealed that the ankle was significantly ($p < 0.05$) more plantarflexed in the minimalist footwear in relation to each of the other shoe conditions. A main effect ($p < 0.05$, $\eta^2 = 0.24$) was also observed for sagittal plane range of motion. Post-hoc analyses proved that range of motion was significantly ($p < 0.05$) larger in the minimalist footwear than in each of the other shoe conditions.

In the coronal plane, a main effect ($p = 0.006$, $\eta^2 = 0.40$) was shown for the angle at footstrike. Post-hoc pairwise comparisons revealed that the ankle was significantly ($p < 0.05$) more inverted in the minimalist footwear in relation to each of the other shoe conditions. In addition, a main effect ($p = 0.03$, $\eta^2 = 0.30$) was observed for the magnitude of peak inversion. Post-hoc analysis proved that peak inversion was significantly larger in the minimalist footwear than in each of the other shoe conditions.

In the transverse plane, a main effect ($p = 0.006$, $\eta^2 = 0.41$) was shown for the angle at footstrike. Post-hoc pairwise comparisons revealed that the ankle was significantly ($p < 0.05$) more internally rotated in the minimalist footwear in relation to each of the other shoe conditions. In addition, a main effect ($p = 0.03$, $\eta^2 = 0.29$) was observed for the magnitude of peak internal rotation. Post-hoc analysis proved that peak internal rotation was significantly larger in the minimalist footwear than in each of the other shoe conditions.

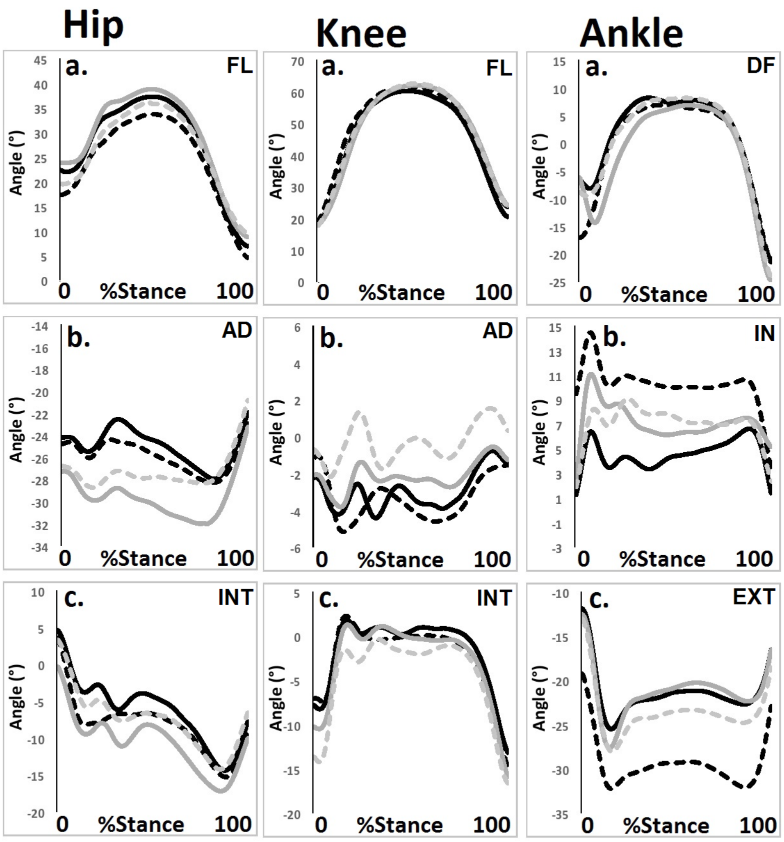

Figure 3. Hip, knee, and ankle joint kinematics in the a. sagittal, b. coronal, and c. transverse planes. Black – energy return, dash – minimalist, grey – court, grey dash – conventional; FL – flexion, DF – dorsiflexion, AD – adduction, IN – inversion, INT – internal, EXT – external

Table 1. Hip joint kinematics as a function of footwear

	Minimalist		Conventional		Court		Energy return		*p* value	η^2	MCID
	mean	*SD*	*mean*	*SD*	*mean*	*SD*	*mean*	*SD*			
Sagittal plane											
Angle at footstrike	17.34	12.08	19.54	11.38	23.68	12.29	22.35	13.84	0.52	0.09	4.13
Peak flexion	34.50	12.79	37.19	12.61	39.88	14.29	38.47	16.75	0.63	0.07	4.70
Range of motion	17.16	3.04	17.65	5.29	16.20	4.69	16.12	5.86	0.82	0.04	1.57
Coronal plane											
Angle at footstrike	–24.80	7.42	–26.76	6.91	–27.13	7.20	–24.19	5.30	0.09	0.24	2.24
Peak adduction	–31.53	8.54	–31.98	8.46	–35.60	8.47	–31.24	6.16	0.42	0.11	2.64
Range of motion	6.73	7.15	5.23	3.69	8.47	4.84	7.05	5.78	0.71	0.06	1.79
Transverse plane											
Angle at footstrike	3.59	9.42	3.34	8.16	–0.20	7.71	4.62	8.18	0.32	0.13	2.79
Peak external rotation	–16.83	7.84	–15.78	8.82	–19.62	8.63	–15.98	8.26	0.08	0.24	2.80
Range of motion	20.42	6.69	19.11	5.16	19.42	3.88	20.60	5.93	0.89	0.03	1.80

MCID – minimal clinically important differences

Table 2. Knee joint kinematics as a function of footwear

	Minimalist		Conventional		Court		Energy return		*p* value	η^2	MCID
	mean	*SD*	*mean*	*SD*	*mean*	*SD*	*mean*	*SD*			
Sagittal plane											
Angle at footstrike	18.52	6.50	17.48	4.30	17.82	4.82	18.28	4.39	0.98	0.01	1.67
Peak flexion	62.22	9.61	63.21	6.94	62.99	7.84	61.35	5.73	0.95	0.01	2.51
Range of motion	43.70	6.16	45.73	4.57	45.17	5.10	43.07	2.57	0.41	0.11	2.53
Coronal plane											
Angle at footstrike	–1.14	2.91	–2.10	3.50	–0.72	3.60	–2.23	3.47	0.68	0.06	1.77
Peak abduction	–7.74	3.09	–7.90	3.68	–6.96	3.83	–8.31	4.21	0.74	0.05	1.53
Range of motion	6.60	3.53	5.80	2.57	6.24	2.75	6.08	2.48	0.72	0.05	0.94
Transverse plane											
Angle at footstrike	–7.05	8.70	–10.22	13.38	–13.33	13.08	–7.78	9.25	0.09	0.23	3.70
Peak internal rotation	5.32	5.57	4.59	6.95	2.28	8.26	5.03	6.54	0.08	0.24	2.28
Range of motion	12.37	4.74	14.82	7.06	15.62	5.61	12.81	5.87	0.40	0.11	1.94

MCID – minimal clinically important differences

Kinetics

A main effect ($p = 0.006$, $\eta^2 = 0.40$) was shown for peak tibial acceleration. Post-hoc pairwise comparisons revealed that peak tibial accelerations were significantly ($p < 0.05$) larger in the minimalist and court footwear in relation to the conventional and energy return conditions. Main effects were also observed for tibial acceleration slope ($p = 0.02$, $\eta^2 = 0.32$) and instantaneous tibial acceleration slope ($p = 0.03$, $\eta^2 = 0.31$). Post-hoc analyses proved that both tibial acceleration slope and instantaneous tibial acceleration slope were significantly larger in the minimalist and court footwear than in the conventional and energy return conditions.

Finally, a main effect ($p = 0.001$, $\eta^2 = 0.49$) was shown for instantaneous load rate. Post-hoc pairwise comparisons revealed that instantaneous load rate was significantly ($p < 0.05$) larger in the minimalist and court footwear in relation to the conventional and energy return conditions.

Discussion

The aim of the current investigation was to examine the effects of different footwear on the kinetics and kinematics of a change of direction task. To the author's knowledge, this represents the first comparative investigation to quantify the effects of different footwear on the biomechanics of a change of direction movement. Research of this nature may provide important new information to athletes regarding the selection of appropriate footwear.

Table 3. Ankle joint kinematics as a function of footwear

	Minimalist		Conventional		Court		Energy return		*p* value	η^2	MCID
	mean	*SD*	*mean*	*SD*	*mean*	*SD*	*mean*	*SD*			
Sagittal plane											
Angle at footstrike	–17.10	10.99	–8.84	15.97	–6.35	12.16	–6.46	13.38	0.04	0.26	4.38
Peak dorsiflexion	8.30	8.49	12.96	4.50	10.60	6.01	13.45	4.35	0.19	0.18	1.95
Range of motion	25.40	12.00	21.80	18.38	16.95	16.14	19.91	13.90	0.04	0.24	5.04
Coronal plane											
Angle at footstrike	9.37	10.20	1.78	4.31	2.35	5.32	1.16	6.75	0.006	0.40	2.21
Peak inversion	16.36	11.21	11.86	6.03	12.61	4.14	10.12	3.78	0.03	0.30	2.10
Range of motion	7.00	3.58	10.08	2.69	10.26	3.31	8.96	3.73	0.18	0.18	1.11
Transverse plane											
Angle at footstrike	–19.24	7.46	–13.05	2.61	–12.55	3.50	–11.92	3.67	0.006	0.41	1.44
Peak internal rotation	–34.31	10.81	–29.09	3.40	–28.37	2.74	–26.88	2.74	0.03	0.30	1.64
Range of motion	15.07	6.69	16.04	4.58	15.82	3.46	14.97	5.27	0.95	0.01	1.67

MCID – minimal clinically important differences

Table 4. Kinetic, tibial acceleration and temporal parameters as a function of footwear

	Minimalist		Conventional		Court		Energy return		*p* value	η^2	MCID
	mean	*SD*	*mean*	*SD*	*mean*	*SD*	*mean*	*SD*			
Peak tibial acceleration (g)	6.38	1.01	5.46	0.91	6.35	0.51	4.98	0.69	0.006	0.40	0.46
Tibial acceleration slope (g/s)	218.33	71.99	179.20	143.54	216.53	140.13	159.70	88.94	0.02	0.32	37.05
Instantaneous tibial acceleration slope (g/s)	417.54	76.05	353.20	115.06	440.16	47.82	315.55	60.76	0.03	0.31	24.97
Instantaneous load rate (BW/s)	282.91	135.84	143.19	97.73	326.67	155.54	106.14	71.45	0.001	0.49	38.38
Stance time (s)	0.49	0.10	0.46	0.06	0.46	0.07	0.50	0.05	0.21	0.17	0.02

MCID – minimal clinically important differences

The first key observation from the current investigation is that tibial acceleration and loading parameters were shown to be significantly greater in the minimalist and court shoes in relation to the conventional and energy boost footwear. This finding concurs with the results of Sinclair et al. [18, 23], who demonstrated that minimalist footwear significantly increased both tibial accelerations and vertical rates of loading during running. However, it opposes those of Sinclair et al. [9], who showed that court footwear reduced impact loading in relation to minimalist footwear during a range of functional sports tasks. It is proposed that this finding relates firstly to the absence of midsole cushioning material in the minimalist footwear and the stiffness of the midsole in the court shoes. Importantly, the magnitude of the aforementioned differences in tibial acceleration and loading parameters exceeded the thresholds denoted by the MCID (Table 4). This observation therefore may have clinical significance, given the proposed connection between impact loading and the aetiology of chronic pathologies [24, 25]. Therefore, the current investigation suggests that minimalist and court footwear may place athletes performing maximal 180° cutting manoeuvres at increased risk from impact related injuries compared with the conventional and energy boost shoes.

The kinematic analysis indicated that the ankle was in a significantly more plantarflexed position at footstrike in the minimalist footwear in relation to the remaining shoe conditions. This points out that the participants adopted a distinct foot contact position in the minimalist footwear. This finding concurs with the previous observations of running studies performed by Squadrone and Gallozzi [26] and Sinclair et al. [18, 23], and the 45° cutting study by Sinclair et al. [9], who each showed a more plantarflexed ankle position when wearing minimalist footwear. Once again it is proposed that this observation is due to the lack of midsole cushioning in the minimalist footwear, whereby the participants adopted this movement pattern in order to reduce the loads experienced by the body.

In addition, the findings from the current investigation showed that the peak angle of inversion was significantly larger in the minimalist footwear as compared with the remaining footwear conditions. It is proposed that this observation relates to the nature of minimalist shoes, as they do not feature any ankle support mechanisms and thus provide reduced resistance to ankle inversion. Once again the differences in inversion parameters between the footwear exceeded the thresholds denoted by the MCID (Table 3). This observation therefore may similarly have clinical significance as excessive ankle inversion is strongly associated with the aetiology of ankle sprain injuries [11]. Therefore, the findings from the current investigation indicates that minimalist footwear may place runners at increased risk from inversion pathologies during maximal 180° cutting manoeuvres.

Finally, the present study showed that the minimalist footwear was associated with significantly larger internal rotation of the ankle at footstrike in relation to the remaining shoe conditions. It is likely, given a maximal change of direction task, that this is a response to the increase in plantarflexion at footstrike, which was also observed in the minimalist footwear condition. It is proposed that participants may have increased the internal rotation of their ankle in response to the flatter foot position in order to provide a more stable platform from which to produce the desired 180° movement.

Conclusion

In conclusion, although the biomechanical effects of different footwear have been examined extensively, the current knowledge regarding differences in kinetics and kinematics when performing 180° change of direction tasks is limited. The present study therefore adds to the knowledge by providing a comprehensive evaluation of both kinetic and kinematic parameters when performing 180° change of direction tasks in minimalist, conventional, energy return, and court footwear. Importantly, the study showed that impact loading parameters were greater in minimalist and court footwear compared with conventional and energy return footwear. In addition, the minimalist footwear was also associated with increased indices of ankle inversion in relation to the other shoe conditions. Therefore, the findings from the current investigation indicate that minimalist and court footwear may place athletes at increased risk from injury when performing this movement.

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